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1374982

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APPLICATION NUMBER: ***60/603,843***
FILING DATE: ***August 23, 2004***
RELATED PCT APPLICATION NUMBER: ***PCT/US05/29815***

UNITED STATES PATENT AND TRADEMARK OFFICE
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Under Secretary of Commerce
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082304 16805 U.S. PTO

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No.	EV 285056723 US

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
A.N.M. Masum	Choudhury	Naperville, IL
Thomas R.	Stanczyk	Lisle, IL
Dean	Richardson	Wilmette, IL

U.S. PTO 60/603843 082304 17497

☑ *Additional inventors are being named on the* 1 *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

SYSTEM AND METHOD OF IMPROVING LIGHT COUPLING EFFICIENCY BETWEEN SILICON WAVEGUIDES AND OPTICAL FIBERS

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

☐ Customer Number 23683 → *Place Customer Number Bar Code Label here*
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OR

☑ Firm *or* Individual Name	Romi N. Bose				
Address	Molex Incorporated				
Address	2222 Wellington Court				
City	Lisle	State	Illinois	ZIP	60532
Country	USA	Telephone	630/527-4419	Fax	630/416-4962

ENCLOSED APPLICATION PARTS *(check all that apply)*

☑ Specification *Number of Pages* 5
☑ Drawing(s) *Number of Sheets* 2
☐ Application Data Sheet. See 37 CFR 1.76
☐ CD(s), Number
☐ Other (specify)

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☐ Applicant claims small entity status. See 37 CFR 1.27.
☐ A check or money order is enclosed to cover the filing fees
☑ The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number: 50-1873
☐ Payment by credit card. Form PTO-2038 is attached.

FILING FEE AMOUNT ($): $160.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☑ No.
☐ Yes, the name of the U.S. Government agency and the Government contract number are: ____________

Respectfully submitted,

SIGNATURE ____________

Date 08/23/2004

TYPED or PRINTED NAME Romi N. Bose

REGISTRATION NO. *(if appropriate)* 43,322

TELEPHONE 630/527-4419

Docket Number: A5-013PROV-US

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

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FEE TRANSMITTAL for FY 2004

Effective 10/01/2003. Patent fees are subject to annual revision.

☐ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT ($) 160

Complete if Known	
Application Number	
Filing Date	
First Named Inventor	A.N.M. Masum Choudhury
Examiner Name	Unknown
Art Unit	Unknown
Attorney Docket No.	A5-013 PROV US

METHOD OF PAYMENT *(check all that apply)*

☐ Check ☐ Credit card ☐ Money Order ☐ Other ☐ None

☑ Deposit Account:

Deposit Account Number: 50-1873

Deposit Account Name: Molex Incorporated

The Director is authorized to: *(check all that apply)*

☑ Charge fee(s) indicated below ☑ Credit any overpayments

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FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
1001	770	2001	385	Utility filing fee	
1002	340	2002	170	Design filing fee	
1003	530	2003	265	Plant filing fee	
1004	770	2004	385	Reissue filing fee	
1005	160	2005	80	Provisional filing fee	160

SUBTOTAL (1) ($) 160

2. EXTRA CLAIM FEES FOR UTILITY AND REISSUE

			Extra Claims		Fee from below		Fee Paid
Total Claims	3	-20** =	0	X	9	=	0
Independent Claims	1	- 3** =	0	X	43	=	0
Multiple Dependent					0	=	0

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
1202	18	2202	9	Claims in excess of 20
1201	86	2201	43	Independent claims in excess of 3
1203	290	2203	145	Multiple dependent claim, if not paid
1204	86	2204	43	** Reissue independent claims over original patent
1205	18	2205	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($) 0

**or number previously paid, if greater; For Reissues, see above

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
1051	130	2051	65	Surcharge - late filing fee or oath	
1052	50	2052	25	Surcharge - late provisional filing fee or cover sheet	
1053	130	1053	130	Non-English specification	
1812	2,520	1812	2,520	For filing a request for *ex parte* reexamination	
1804	920*	1804	920*	Requesting publication of SIR prior to Examiner action	
1805	1,840*	1805	1,840*	Requesting publication of SIR after Examiner action	
1251	110	2251	55	Extension for reply within first month	
1252	420	2252	210	Extension for reply within second month	
1253	950	2253	475	Extension for reply within third month	
1254	1,480	2254	740	Extension for reply within fourth month	
1255	2,010	2255	1,005	Extension for reply within fifth month	
1401	330	2401	165	Notice of Appeal	
1402	330	2402	165	Filing a brief in support of an appeal	
1403	290	2403	145	Request for oral hearing	
1451	1,510	1451	1,510	Petition to institute a public use proceeding	
1452	110	2452	55	Petition to revive - unavoidable	
1453	1,330	2453	665	Petition to revive - unintentional	
1501	1,330	2501	665	Utility issue fee (or reissue)	
1502	480	2502	240	Design issue fee	
1503	640	2503	320	Plant issue fee	
1460	130	1460	130	Petitions to the Commissioner	
1807	50	1807	50	Processing fee under 37 CFR 1.17(q)	
1806	180	1806	180	Submission of Information Disclosure Stmt	
8021	40	8021	40	Recording each patent assignment per property (times number of properties)	
1809	770	2809	385	Filing a submission after final rejection (37 CFR 1.129(a))	
1810	770	2810	385	For each additional invention to be examined (37 CFR 1.129(b))	
1801	770	2801	385	Request for Continued Examination (RCE)	
1802	900	1802	900	Request for expedited examination of a design application	

Other fee (specify) ________________

*Reduced by Basic Filing Fee Paid

SUBTOTAL (3) ($) 0

SUBMITTED BY				(Complete *(if applicable)*)
Name *(Print/Type)*	Romi N. Bose	Registration No. (Attorney/Agent)	43,322	Telephone 630-527-4419
Signature	[signature]			Date 8-23-2004

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PROVISIONAL APPLICATION COVER SHEET
Additional Page

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Docket Number	A5-013PROV-US

INVENTOR(S)/APPLICANT(S)

Given Name (first and middle [if any])	Family or Surname	Residence (City and either State or Foreign Country)
Ariela	Donval	ISRAEL
Ram	Oron	ISRAEL
Moshe	Oron	ISRAEL

Number 1 of 1

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SYSTEM AND METHOD OF IMPROVING LIGHT COUPLING EFFICIENCY BETWEEN SILICON WAVEGUIDES AND OPTICAL FIBERS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to planar lightwave circuits and, more particularly, to efficiently coupling light from a standard optical fiber to a silicon waveguide.

2. Description of the Related Art

Planar Lightwave Circuits (PLCs) are intended to transmit and receive signals for short distance data as well as long distance telecommunication systems. For optimal operation, the PLCs must have functional optical components, such as waveguides. These must be small enough in size so that dense integration of devices, including sharp bends in the waveguides, is possible on a single chip.

High-index-contrast material systems, such as a core layer of silicon, on a Silicon On Insulator (SOI) substrate, having a refractive index of ~ 3.5, surrounded by a silica clad with a refractive index of ~ 1.5, offer stronger light confinement in smaller dimensions. One such SOI substrate is shown in figure 1. There could be many practical uses of high-index-contrast waveguide chips, especially in telecommunications, where there is an emphasis on developing ways for routing and processing multi-wavelength optical signals transparently (without converting optical signal to electrical signals and back again). One such example is single mode waveguide based "mux" and "demux" for serializing and separating multi-wavelength optical signals in Dense Wavelength Division Multiplexing (DWDM) application. For this kind of application and others, it is generally desirable to configure the waveguides in single mode propagation to avoid introduction of undesirable effects of differing propagation velocities of different modes.

One of the most difficult challenges facing high-index-contrast optical systems is efficiently coupling light into and out of the chip. Particularly difficult is the coupling of light from a standard optical fiber or external source to a silicon waveguide. A large mismatch between the common optical fiber dimension and that of the high-index-contrast waveguide, and their respective mode sizes, complicates light coupling from one to the other.

A number of techniques have been utilized for optical coupling between waveguides and optical fibers, including prism couplers, grating couplers, tapered fibers and micro-lens

mode transformers. Unfortunately, none of these techniques offer the combination of high coupling efficiency, wavelength independence, reliability, manufacturability, ruggedness, and robustness demanded for use in a low-cost high-volume telecommunications environment.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic of an SOI structure in accordance with the present invention;

FIG. 2. is a conceptual schematic of a 3-D tapered waveguide in accordance with the present invention;

FIG. 3 is a scanning electron microscopic view of a 3D waveguide step; and

FIG. 4 is a Profilometer scan showing 9 etched steps of a 3-D waveguide.

DETAILED DESCRIPTION

In order to effectively couple light from optical fibers to high-index-contrast single mode waveguides, there is provided, as an integral waveguide extension, a waveguide section between the waveguide and the fiber that is tapered vertically and also laterally.

In FIG. 2, there is shown a 3-D tapered section that acts as a classic adiabatic modal transformer that transforms the input fundamental mode shape (that is matched to the mode shape of the optical fiber) to that of the waveguide mode making the light coupling more efficient than that with no taper at all. In order to further increase coupling efficiency a special High Numerical Aperture (HNA) fiber may be used as the input fiber. A special splice program is used for coupling a regular SMF28 into our HNA fiber with overall typical loss of 0.2 dB. An intermediate step toward the 3-D taper is the 2-D taper. The 2-D taper is a lateral taper with coupling efficiency lower than that of the 3-D taper, and requires less technological effort.

Turning to FIG. 1, the starting material for fabricating 2-D and 3-D waveguides growing crystalline silicon on insulator (SOI) structures is shown. The insulator is a 2 μm thick layer of thermally grown SiO_2 on 6" silicon substrates. A 3 μm thick layer of crystalline silicon is deposited on top of SiO_2 to complete the structure.

Next, as shown in FIG. 2, the mask that initially defines the waveguides on the wafer has various width dimensions starting from 0.5 μm up to 3μm with an increment of 0.25 μm. At the end of the waveguides, there is included a 2-D flare that extends from the waveguide width to a width of 4 μm within a horizontal distance of 250 μm. This taper is necessary to match the mode field diameter (MFD) of the high numerical aperture (HNA) fiber to that of

the waveguide in the horizontal direction. First the 2-D waveguides are defined and etched in the wafer. Subsequent step etches are performed to create a taper along the wafer thickness in the 2-D flare area so that there is also a MFD match between the HNA fiber and the waveguide in the vertical direction.

To define the sub-micron width waveguides, a photolithography technique using AZ P4110 i-line (365 nm) photoresist and a Karl Suss MA6 mask aligner is provided. Next the waveguides are etched using the Oxford silicon dry etching system. C_4F_8 (flow rate 90 sccm) + SF_6 (flow rate 50 sccm) etch chemistry is utilized in the Oxford machine for etching. The measured average depth of the waveguides is ~1 μm.

As shown in FIG. 3, a 3-D taper step is then used wherein the entire waveguide is covered with Shipley 1818 positive photoresist. Using an appropriate mask the waveguide is then exposed to UV light leaving only 25 μm of unexposed areas at the two ends. Dry etching, using the previous chemistry in the Oxford machine is then performed to achieve a 0.167 μm step. By way of example, FIG. 4 illustrates several more 0.167 μm deep steps being etched at the two ends of the waveguides to complete the 3-D taper process. The space between each step is 25 μm. The total etch depth is 1.5 μm.

The wafer is then diced into appropriate pieces and cleaned. A 2 μm thick SiO_2 top cladding layer is e-beam evaporated to complete the waveguide structure. The two ends of the waveguides are then mechanically polished to a mirror finish. It is possible to measure the coupling and propagation loss in the waveguides without any AR coating deposition. For real coupling loss improvement an AR coating is necessary at the two ends.

An appropriate optical measurement setup that includes a 1550 nm DFB laser, a 24 dBm amplifier, HNA input fiber, a microscope objective and a free space InGaAs detector is used to determine the propagation loss in the waveguides and the coupling loss between HNA fiber and the waveguide. A comparison between at least 3 lengths of waveguide is used to find out the waveguide propagation loss value. Measurements of waveguide loss for 3-D, 2-D and no taper waveguide samples produce the coupling efficiency of each taper.

It is to be noted that theoretical calculations using commercially available software packages (by Photon design, Rsoft) was used to predict coupling loss of 1.8 dB between the HNA fiber and the 3-D waveguides. The actual measurement produced a coupling loss of about 2 dB, very close to the theoretical prediction. For comparison, a 2-D taper is measured to have around 4 dB coupling loss. Without any taper, the coupling loss is larger than 8 dB.

The invention described in the above description is not intended to be limited to the specific form set forth herein, but on the contrary, it is intended to cover such alternatives, modifications, and equivalents as can reasonably be included within the spirit and scope of the appended claims. In particular, the various dimensions and measurements provided above are by way of example only and may be varied as needed. In addition, the present invention also may be used equally as well in non-imaging light concentrators.

CLAIMS

What is claimed is:

1. A method for coupling light between a waveguide and an optical fiber, comprising:

providing a waveguide extension located between the waveguide and the optical fiber; and

tapering the waveguide.

2. The method of claim 1, wherein the waveguide extension is tapered vertically.

3. The method of claim 1, wherein the waveguide extension is tapered horizontally.

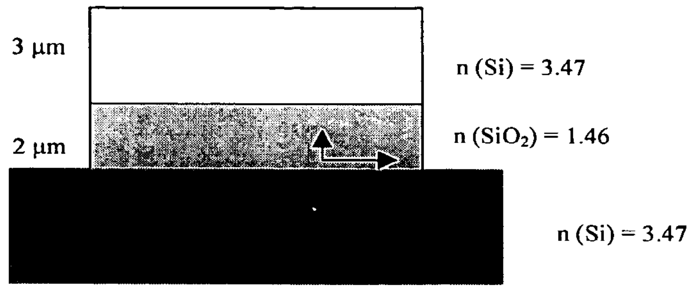
3 μm
2 μm
n (Si) = 3.47
n (SiO2) = 1.46
n (Si) = 3.47

FIG. 1

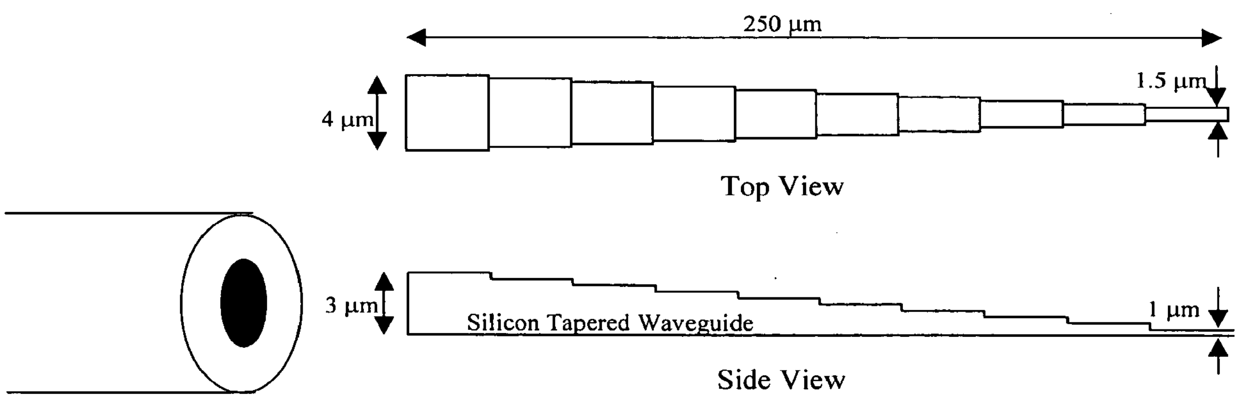
250 μm
4 μm
1.5 μm
Top View
3 μm
Silicon Tapered Waveguide
1 μm
Side View

FIG. 2

SYSTEM AND METHOD OF IMPROVING LIGHT COUPLING EFFICIENCY BETWEEN SILICON WAVEGUIDES AND OPTICAL FIBERS
Attorney Docket No.: A5-013 PROV US
630/527-4419

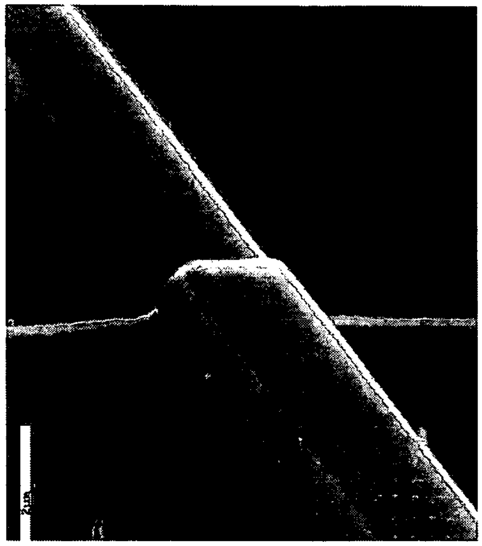

FIG. 3

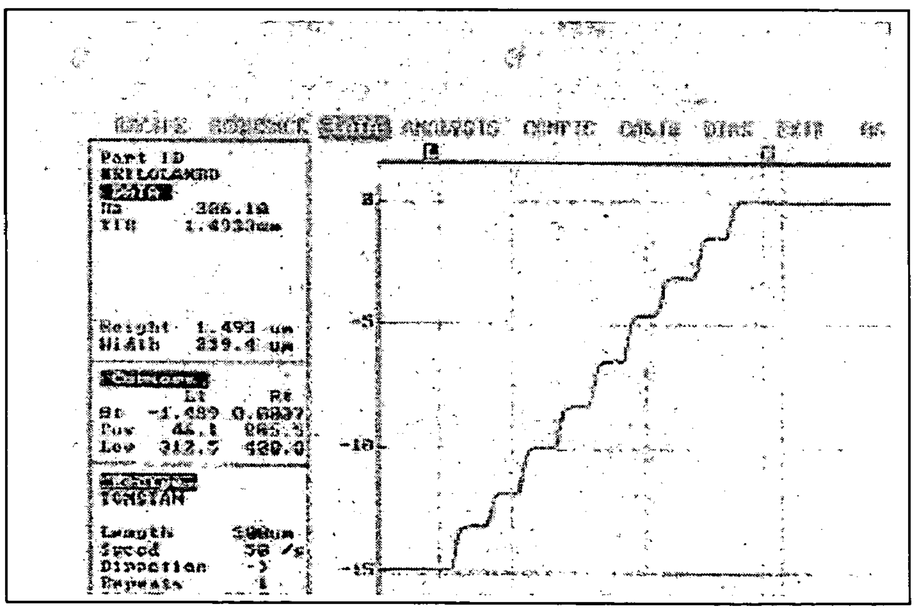

FIG. 4